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B. R. Clemesha, G. S. Kent,
J. R. Koster, & R. W. Wright

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EQUATORIAL STUDY OF IRREGULARITIES IN THE IONOSPHERE

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ERRATA

(a) On page 47, Part (V) "The patches are usually observed to drift from east to west......" should read, to agree with the foregoing text, "from west to east".

(b) On page 38, par. 2 "Fig. 10" should read "Fig. 11".

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AF 61 (052)-421

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12th. August 1963.

FINAL REPORT

October 1960 through August 1963

EQUATORIAL STUDY OF IRREGULARITIES IN THE IONOSPHERE.

B.R. Clemesha,[1] G.S. Kent,[2] J.R. Koster[1]
and R.W.H. Wright.[3]

1. Department of Physics, University of Ghana.
2. Department of Physics, University College of Ibadan.
3. Department of Physics, University of the West Indies.

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Preface.

This report covers work carried out under contract AF 61 (052)-421 during the period October 1960 through August 1963. The principal work on this contract has been concerned with a study of F region irregularities using the back-scatter technique, and hence this study is reported here in some detail, although some of the work has already been presented in previous reports. Various other studies, which have been fully reported elsewhere, are reported here only briefly, references being given to the appropriate Technical Reports or Notes in which a full description of the experiments appeared.

Research on this contract was carried out under the general direction of Professor R.W.H. Wright.

Technical Notes and Reports previously reproduced under contract AF 61(052)-421.

Notes

1. The height of night-time F layer irregularities at the equator.
   G.S. Kent, and J.R. Koster, 9th September,1961.
   (1961, Nature, 191, 1083)

2. Scattering of radio waves in the ionosphere.
   B.R. Clemesha, and R.W.H. Wright, 6th January, 1962.
   (1962, Nature, 193, 54)

3. The elongation of irregularities in the equatorial ionosphere.
   B.R. Clemesha, 20th July, 1962
   (1963, J. Geophys. Res., 68, 2363)

4. A rotating aerial back-scatter sounder
   B.R. Clemesha, 10th August, 1962.

Reports

Annual Summary Report No.1. R.W.H. Wright, January 1962.

Annual Summary Report No.2. B.R. Clemesha, G.S. Kent, J.R. Koster and R.W.H. Wright, March 1963.

CONTENTS OF THIS REPORT

Field strength measurements of the transmissions from the Thule and Fairbanks back-scatter sounders.

B.R. Clemesha & R.W.H. Wright.

It was originally intended that the observation 12, 18 and 30 Mc/s. signals from the back-scatter sounders located at Thule and Fairbanks should constitute a major part of the research on this contract. The equipment for monitoring these signals did not arrive in Ghana until December 1960, and hence there was some delay in starting the project. Owing to the fact that part of the equipment was lost during shipment, part damaged, and no aerial towers were shipped, it was not possible to start measurements until February 1961. When measurements were commenced, it was found that interference on both Thule and Fairbanks 12 Mc/s. channels, and Fairbanks 18 Mc/s. channel, made monitoring impossible on these frequencies; the Thule 18 Mc/s. channel was free from interference at least part of the time.

The 18 Mc/s. signal from Thule was monitored for a period of 7 months, April through October 1961, but interference made the data too sparse for anything other than monthly mean diurnal variations to be obtained. After October 1961 increases in interference, and decreases in signal strength made any further work on this project pointless, and the experiment was closed down.

The full results from this study are given in Annual Report No.1, conclusions were briefly as follows:

(i) Between the hours of 0600 and 0100 G.M.T., April through August 1961, the strength at Accra of the signals from the 4 KW. 17.695 Mc/s. transmitter located at Thule was normally greater than 1 microvolt.

(ii) The intensity of interfering signals on the 12 Mc/s. channels made monitoring on this frequency pointless, signals from Thule being observed on two occasions only.

(iii) The strength at Accra of the 30 Mc/s. signal from Thule never exceeded 1 microvolt.

Group-delay measurements on the 16.570 Mc/s. pulsed transmissions from Freiburg. B.R. Clemesha, & R.W.H. Wright.

This experiment was intended to obtain information on multi-path propagation between Freiburg in Germany, and Accra in Ghana. Initial difficulties were experienced in connection with the stabilities of the time reference oscillators both at Freiburg and Accra, these difficulties were finally overcome when a stable 100 Kc/s. oscillator was installed at Freiburg, and a similar oscillator, with a stability of the order of a few parts in 10^8 per day, was constructed at Accra. A number of group delay records were obtained during 1961, but their extreme complexity (at times, as many as ten separate modes were present) made any immediate analysis impossible. It was intended that these records

should be analysed with the aid of a back-scatter information from both the Freiburg and Accra terminals, but owing to a decrease in the funds available for research under this contract it was necessary to abandon the project. A more complete description of this experiment appears in Annual Summary Report No.1.

<u>An investigation of irregularities in the night-time equatorial F region</u>. G.S. Kent & J.R. Koster.

The purpose of this experiment was to determine the height of the irregularities in the night-time F region which give rise to the scintillation of satellite signals. The experimental technique was one of recording the fading of the 108 Mc/s. signal from an artificial earth satellite at three spaced receivers, and obtaining the required information by correlating the three signals. It was found that the effective height of the irregularities was always between 50 and 100 Km. above the base of the F layer, and that the thickness of the scattering region was not greater than 120 Km. This experiment was fully described in Technical Note No.1 (Kent and Koster 1961).

Further studies, of a similar nature to those described above were carried out at the end of 1962. These studies were designed to provide a more detailed investigation of the F region irregularities causing scintillation.

Measurements were made on the signals from ten different satellites having transmissions on the 136 Mc/s. band. A very considerable amount of data was collected, and, owing to its great

complexity, its analysis is not yet complete. The information was originally recorded in analogue form on magnetic tape, and has now been digitalised, ready for computing, by a manual reduction process. As the University's own computer will not be in operation until later this year, the digital data has been sent to the Cambridge Mathematical Laboratory for computing. The results of this experiment will be published when the analysis is complete.

The scattering of radio waves from the ionosphere

B.R. Clemesha & R.W.H. Wright.

This investigation was a theoretical study of the factors controlling the scatter of medium frequency radio waves in the D region. The study demonstrated that the apparent maximum, observed at a height of about 70 Km., in the back-scatter of radio waves with frequencies of the order of 2 Mc/s. does not, as has hitherto been supposed, require the postulation of a maximum in the electron density, or intensity of irregularities, at this height. A full description of this study appears in Technical Note No.2 (Clemesha and Wright, 1962).

The elongation of irregularities in the equatorial ionosphere.

B.R. Clemesha.

In this experiment the weakly scattered signals of a 2.4 Mc/s. pulse transmitter were recorded at three spaced receivers; the signals were scattered from irregularities in the ionosphere at heights between 70 and 110 Km. By carrying out a correlation analysis, on the fading records from the three receivers, the shape of the diffraction

pattern on the ground was obtained for signals scattered at various heights. It was shown that for signals scattered from below a height of 90 Km. the pattern was only slightly elongated in the direction of the geomagnetic field, but that for signals scattered from greater heights the elongation increased rapidly with height. It was shown theoretically that initially isotropic irregularities would be expected to diffuse anisotropically at heights above 90 Km., but not at lower heights. This experiment was fully described in Technical Note No.3 (Clemesha, 1962).

Measurements on the sunset fading effect.

J.R. Koster.

The sunset fading effect, or flutter fading, is a phenomenon sometimes observed on radio signals reflected from the F region of the ionosphere when the reflection point is near to the magnetic equator. The effect was investigated in Ghana, first using direct observation of variations in the carrier level of a broadcast transmission from England, and later with the aid of a fading rate meter. It was found that flutter fading occured between sunset and midnight, that it most frequently occured at, or shortly after the equinoxes, and that it correlated positively with sunspot cycle. The rate of fading was found to be directly proportional to the carrier frequency of the signal observed, and the occurence of flutter fading was shown to correlate with radio star scintillation. It was concluded that flutter fading is the result of the beating together

of two signals, the one propagated by a normal reflection process, and the other by coherent scatter from elongated irregularities in the F region, the signal propagated by this latter process having a doppler shift imposed upon it by the motion of the irregularities.

A full description of this experiment appears in Annual Summary Report No.2, and has also been published (Koster, J.R. 1963, J. Geophys. Res., 68, 2571).

AN INVESTIGATION OF THE IRREGULARITIES IN THE F REGION ASSOCIATED WITH EQUATORIAL TYPE SPREAD-F

B.R. Clemesha.

Abstract.

The results are given of an investigation of spread-F irregularities, using a back-scatter radar operating on a frequency of 18 Mc/s. The irregularities are shown to occur in patches which extend over distances of up to 400 Km. in the east-west vertical plane. Seasonal and nocturnal variations in the occurrence of irregularities are given, and it is shown that variations in their height closely follow variations in the height of the F layer. The drift velocity of patches of irregularities is shown to be of the order of 100 m/s. towards the east. The results of doppler shift measurements are interpreted as indicating that the irregularities sometimes exhibit large vertical velocities. It is shown that the irregularities are anisometric in the east-west vertical plane, and appear to have a maximum scattering cross-section in the direction perpendicular to their direction of motion.

1. Introduction.

The experiments described in this paper were designed to investigate the irregularities in the F region which are associated with equatorial type spread-F. The spread-F which is observed at equatorial latitudes varies in its appearance during tho night (Lyon et. al. 1961), but may be divided into two basic types, which have been termed equatorial typo and temperate latitude type respectively, the former occurring chiefly before midnight, and the latter mainly after midnight. Calvert and Cohon (1961) have shown that most of the equatorial type spread-F configurations observed on ionograms may be synthesised by ray tracing, assuming one or more patches of irregularities which may be situated below, near to, or above the height of maximum F region ionisation, and which scatter in the east-west vertical plane. The fact that the scattering is confined to the east-west vertical plane is due to the fact that the irregularities are elongatod, and that the direction of elongation is parallel to the earth's magnetic field, which at equatorial latitudes is, of course, nearly horizontal. Temperate latitude type spread-F has been attributod, by Pitteway and Cohen (1961), to 'waveguide' scattering in tho north-south vertical plane.

Whilst the ionosonde method of studying spread-F has provided valuable data as far as the occurrence and geomorphology of spread-F are concerned, it is not well suited to a detailed study of the irregularities which cause spread-F. As it is known that some of the irregularities responsible for spread-F are capable of scattering radio waves with frequencies well above the critical frequency of the F region, it was decided to carry out an investigation of the F region irregularities using a back-scatter radar operating on a frequency of 18 Mc/s.; the advantages of such a system are as follows. (i) By operating at a fixed frequency it is possible to use aerials of fairly high gain, thus increasing the sensitivity of the sounder over that of a normal ionosonde. (ii) The use of a fixed frequency enables a directional aerial to be used, and hence the scatter region can be located in direction to a certain degree. (iii) Operating above the critical frequency avoids the danger of confusing scattered signals with totally reflected signals, and simplifies the determination of ray paths.

The apparatus used for the experiments described in this paper consisted basically of an 18 Mc/s. transmitter of 1 KW. peak power, 300 microsecond pulse duration, and a repetition frequency of 16.6, 25, or 50 c/s., used in conjunction with a receiver having a bandwidth of 6 Kc/s. The aerial used was a

three element Yagi, tuned for 18 Mc/s., mounted approximately half a wavelength above the ground, and rotatable about three mutually perpendicular axes in such a way that the aerial could be pointed at any part of the sky with any direction of polarisation. A transmit/receive switch enabled the same aerial to be used for transmitting and receiving.

Proliminary observations were made with the above equipment using an A scan display of echoes, with range markers at 1 mS. intervals. The results from these observations indicated that a method of making a permanent record of the observed echoes was required, and so a plan position indicator (P.P.I.) display system with photographic recording was incorporated into tho equipment. For the purpose of producing P.P.I. pictures the horizontally polarised aerial was made to rotate about a vertical axis at a uniform rate of one revolution per minute. By means of suitable programming equipment it was arranged that P.P.I. photographs were taken at predetermined times and at predetermined aerial olevations (the aerial elevation refers to the vertical angle, from the horizontal, of the axis of the Yagi). The equipment was further developed to enable continuous recording to be made of the range of the direct back-scatter echoes from a given direction. Finally apparatus was added which made it possible to measure the doppler shift of echoes.

2. Direct back-scattered echoes from F region irregularities.

Preliminary measurements were made during March, 1962, using the transmitter and receiver described above. Ground back-scattered echoes of the type normally observed on oblique incidence back-scatter sounders were observed during the daylight hours and much of the night (a ground back-scattered echo is one which has undergone 'specular' reflection by the ionosphere, has been scattered by the ground, and has retraced its path to the sounder), these echoes were found to have a minimum range of about 1000 Km. In addition to the normal ground back-scatter echoes there frequently occurred, during the evening hours, echoes with ranges down to 400 Km. Echoes with the shortest range of 400 Km. were observed at maximum intensity when the aerial was pointing vertically overhead, indicating that the source of the echo was vertically above the sounder. In the light of these observations it was clear that the additional echoes being observed during the evening hours were caused by direct back-scatter from patches of irregularities situated at a height of about 400 Km. in the F region. The following is a description of three experiments designed to obtain more information about the irregularities, and the results of these experiments.

2.1 The P.P.I. measurements.

The recording of 18 Mc/s. back-scatter echoes, using a P.P.I. display, was commenced at the end of April, 1962, and, as

at this stage little was known about the occurrence of these echoes, the equipment was programmed to take one record every hour during the day, every half hour from 1800 G.M.T. to midnight, and every quarter hour 1900 to 2200 G.M.T., this last period being when the echoes were expected to occur most frequently. The aerial elevation for these runs was fixed at 30° to the horizontal, in which position the sounder, although having a maximum sensitivity at an angle of about 20°, was sensitive to echoes from near horizontal to vertical angles of arrival. In addition to the runs at 30° elevation the sounder was programmed to take a series of four consecutive runs at aerial elevations of 5, 30, 60 and 85 degrees every hour from 1900 to midnight, the intention of these runs being to make it possible to distinguish between echoes originating in direct back-scatter from the F region, and ground back-scatter via sporadic E, by enabling an approximate determination of the angle of arrival to be made.

A P.P.I. picture showing direct back-scatter is shown in Fig. 1. In Fig. 1 the normal ground back-scatter may be seen in all directions except north at a range of 1000 to 2000 Km. Two direct back-scatter echoes are present (labelled (a) and (b) in Fig. 1) at ranges of 600 to 900 Km. in the west, and 750 to 950 Km. in the east. It will be noted that for the direct back-scatter echoes the maximum signal strength occurs when the aerial is pointing towards magnetic east or west (the directions of

FIG. I PPI RECORD SHOWING DIRECT BACK-SCATTER,

2030 GMT, 31/10/62.

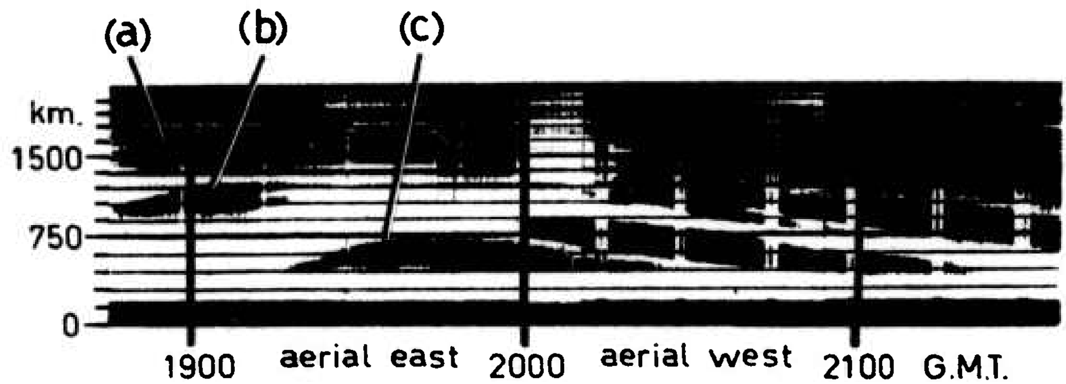

FIG. 2 RANGE/TIME RECORD SHOWING DIRECT BACK-SCATTER,

29/10/62.

geographic and magnetic north are labelled N and H respectively in Fig. 1). The fact that direct back-scatter echoes are observed to the east and west only is due to the well known field alignment of the elongated irregularities responsible for the echoes. Clearly observable, when a large number of records are examined, is a slight tendency for the echoes to occur to the south of east and west, this is due to the fact that Accra is not situated exactly on the magnetic equator, but some 5° south, where the dip angle is 10°. An interesting point to be observed in Fig. 1 is the lack of any ground back-scatter echo from the north. It is frequently observed on the records taken at Accra that echoes in the north have greater range than those in the south, or that no echoes are observed at all in the north. The explanation of this phenomenon is believed to lie in the position of Accra relative to the equatorial anomaly, Accra being some 5° south of the magnetic equator, the F region electron densities 'seen' to the south should frequently be greater than those to the north.

Ground back-scatter echoes via sporadic E are frequently observed during the day, and occasionally observed during the night. It is possible to differentiate between ground back-scatter via patches of Es and direct back-scatter from the F region, by determining the angle of arrival of echoes; however, the appearance of Es echoes was found to be sufficiently

different from that of the direct back-scatter echoes to avoid confusion without measuring the angle of arrival for all echoes.

A full analysis of the P.P.I. measurements made during the spring and autumn of 1962, and the spring of 1963, is given in section 3; the preliminary results of measuremonts made during the spring of 1962 are given below.

(i) Direct back-scatter echoes from field aligned irregularities in tho F region are observed on a frequency of 18 Mc/s.

(ii) Echoes are observed to the east and west only, at ranges from about 400 Km. to 1400 Km.

(iii) Echoes occur most frequently during the period 1900 to 2200 G.M.T.

(iv) Echoes are always observed to come from patches of irregularities, never from a wide distribution of irregularities covering the whole of that part of the F region 'visible' to tho sounder.

2.2 <u>The range versus time measurements</u>.

It was noted, when examining a sequence of P.P.I. records taken at 15 minute intervals, that there often appeared to be a systematic movement of an echo which apparently persisted from one record to the next. It was, however, difficult to be certain that an echo seen on two consecutive records was the same echo, and

therefore difficult to make any measurement of a systematic movement or drift. In order to determine whether or not any such drift did occur, and if so, its direction and velocity, continuous measurements were made of the range of echoes versus time. In order to do this it was arranged that the rest position of the aerial should be such that it pointed either to the east or to the west, and the echoes displayed on an intensity modulated time base, photographed by a camera in which the film moved in a direction at right angles to the direction of the time base. A range/time record showing direct back-scatter echoes is shown in Fig. 2.

In Fig.2, where up until 2000 G.M.T. the aerial is pointing east, and after 2000 G.M.T. it is pointing west, a ground back-scatter echo (a) may be seen at a range of approximately 1500 Km. in the east; in addition to the ground back-scatter echo there are two direct back-scatter echoes (labelled (b) and (c)) at ranges of 1000 Km. and 500 Km. In the west a number of direct back-scatter echoes may be seen at ranges between 450 Km. and 1400 Km. It will be noted that the ranges of direct back-scatter echoes seen to the east increase with time, and that the ranges of echoes seen to the west decrease with time, indicating a drift of irregularity patches from west to east. From the slope of the direct back-scatter traces it is possible to determine a line of sight velocity for the patches. This velocity is found to be of the order of 100 m/s., both for patches

approaching the sounder from the west, and for patches travelling away from the sounder to the east. As the line-of-sight velocities to the east and west are about the same in magnitude it may be assumed that the drift is approximately horizontal. The velocities derived from the range/time records are, of course, east-west components of velocity only, the experiment providing no information about any north-south velocity which might exist.

The full results of this experiment are given in section 3.

2.3 <u>The doppler shift measurements</u>.

The range/time measurements provide information about the drift velocity of patches of irregularities, but, as there is no reason to suppose that individual irregularities necessarily move with the same velocity as the patch, it is important to measure the velocity of the irregularities themselves. As it is the individual irregularities which scatter radio waves, any component of velocity which they have in the direction of the exploring wave-normal must produce a doppler shift of the echo pulse, and hence by measuring the doppler shift it is possible to determine the line-of-sight velocity of irregularities.

The technique used for measuring doppler shift was basically similar to that used in a panoramic radio receiver,

where the pass-band of the receiver is swept through the frequency range which it is desired to examine. The receiver used had a bandwidth of approximately 1 c/s., and could be swept through a range of several hundred cycles per second above or below the transmitter frequency. The frequency spectrum of the received signal was obtained by sweeping the receiver frequency at a uniform rate, and displaying its output on a pen recorder. Difficulties caused by drift of the transmitter and receiver oscillator frequencies were overcome by suitable intercoupling between the oscillators. In order to examine the frequency spectrum of a particular echo, a gating circuit was incorporated at a wide-band stage in the receiver. The technique described above, using a pulse modulated transmission, involves some ambiguity in identifying the echo signal, as the transmitted signal consists of a large number of sideband harmonics of nearly equal amplitude, spaced apart by a frequency equal to the pulse repetition frequency. The ambiguity arises in trying to determine to which transmitted sideband harmonic a received signal belongs. This problem was overcome by making measurements at two different pulse repetition frequencies on the same echo.

Two examples of frequency spectra of direct back-scatter echoes are shown in Fig. 3. In Fig. 3 the spectral lines marked (a) are the sideband harmonics of the transmitted signal (deliberately allowed to leak into the receiver, in order

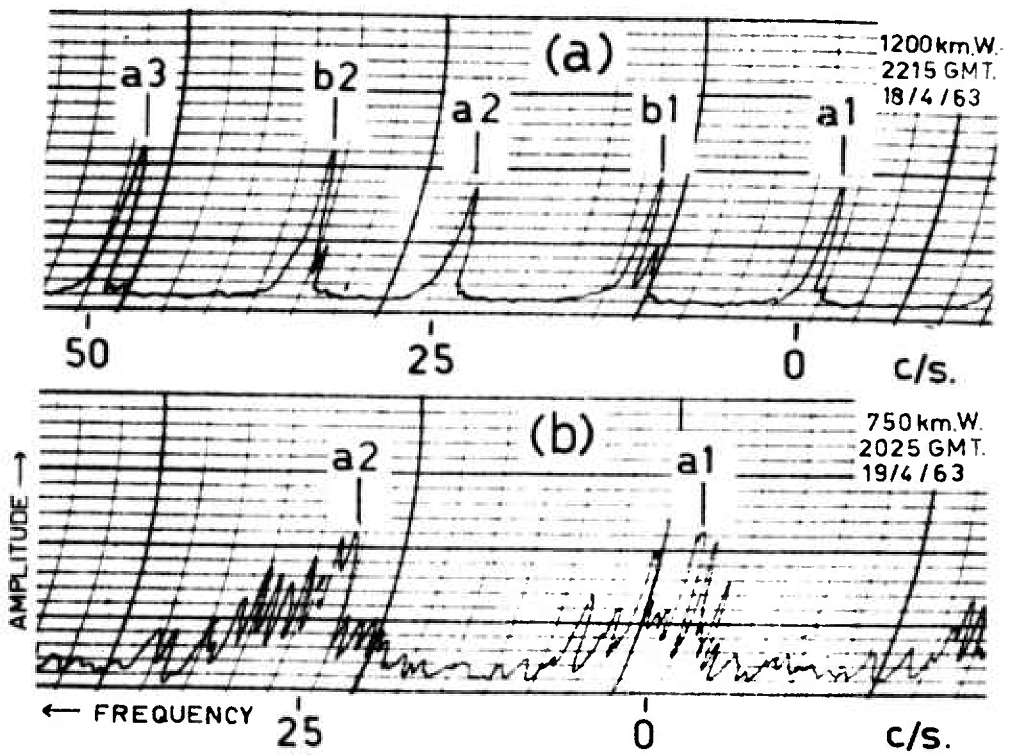

FIG.3 FREQUENCY SPECTRA OF DIRECT BACK-SCATTER ECHOES.

to give a frequency reference), and those marked (b) are the corresponding doppler shifted echo signals. In Fig. 3a, which is for a patch of irregularities to the west of the sounder, the doppler shift is +12 c/s., equivalent to a velocity of 100 m/s. directed towards the sounder, and there is very little spreading of the doppler shifted echo signal, indicating a uniform motion, with little or no random velocity. The doppler spectrum shown in Fig. 3b is again for a patch of irregularities to the west of the sounder, but in this case the doppler shift is only +1 c/s., equivalent to a velocity of 8 m/s. towards the sounder, but with a spread of about 9 c/s., equivalent to a random velocity of the order of 35 m/s. The examples shown are extreme cases, the spread in the doppler spectrum normally being of the order of 4 to 5 c/s.

The full results of this experiment are given in section 3.

3. Results.

3.1 Occurrence of direct back-scatter echoes, seasonal and nocturnal variations.

During the period September to December, 1962, observations were made on a total of 90 nights, on 53 of which direct back-scatter echoes were observed. In the spring of 1963 observations were made on a total of 47 nights in April and May,

direct back-scatter echoes being observed on 23 occasions. Unfortunately, continuous measurements have not been made over a complete year, but sufficient data are available to show a distinct seasonal change. A monthly index of echo occurrence has been calculated by dividing the total number of days on which irregularities were observed, in each month, by the total number of days on which observations were made, and expressing the result as a percentage; the variation of this percentage from September 1962 to June 1963 is shown in Fig. 4. Maximum occurrence appears to be in October-November, and in April-May; no echoes at all were observed in February, although observations were made on 22 nights. It would seem then that there are two maxima in the occurrence of irregularities, one lasting approximately from spring equinox to summer solstice, and the other from autumn equinox to winter solstice, and that the spring maximum is less pronounced than the autumn.

During the autumn of 1962, and the spring of 1963, sufficient measurements were made to determine average nocturnal variations in the occurrence of direct back-scatter echoes. The nocturnal variations for September to December, 1962, and April to May, 1963, are shown in Fig. 5, which shows the average number of echoes visible at a given local time.

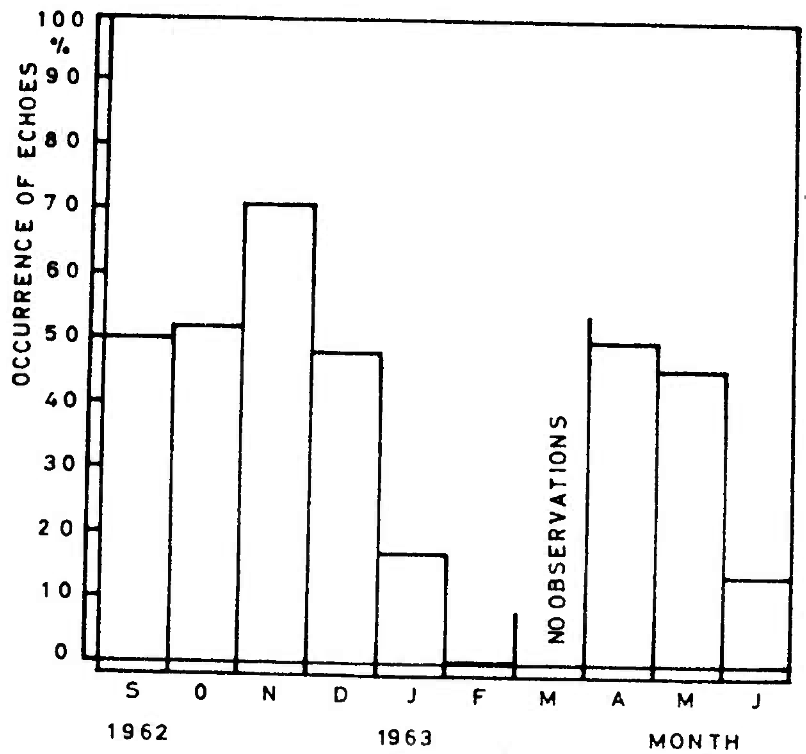

FIG. 4 SEASONAL VARIATION IN OCCURRENCE OF DIRECT BACK-SCATTER.

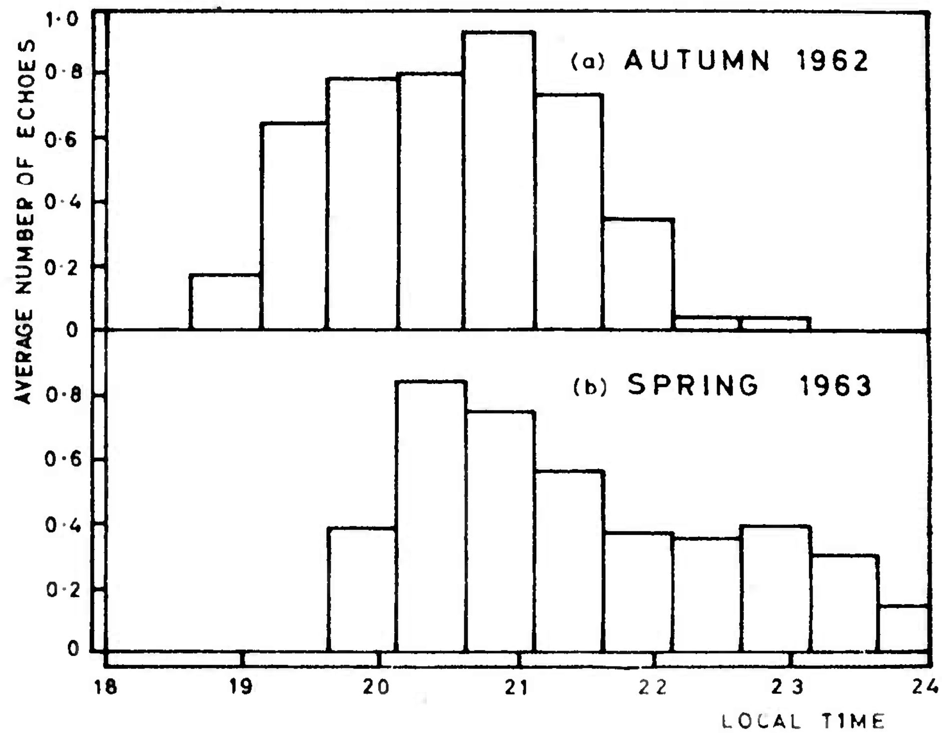

FIG. 5 NOCTURNAL VARIATION IN OCCURRENCE OF DIRECT BACK-SCATTER.

In Fig. 5 the average numbers of patches given rise to echoes were arrived at by averaging, over all those days on which echoes were observed at any time, the numbers of echoes visible at a given time. The sounder can 'see' patches approximately 15° east or west of its location, and therefore Fig. 5 represents the average numbers of patches observed in a 30° wide belt of longitude; in calculating the averages the time of occurrence of a patch was taken as the local time at the position of the patch, rather than the local time at the sounder. The number of patches 'seen' by the sounder does, of course, depend upon the sensitivity of the sounder (as is evidenced by the fall-off with range in the number of patches observed), and hence the actual values given in Fig. 5 are not of any great significance, of more interest is the nocturnal variation in the number of patches observed. It may be seen from Fig. 5a that during the autumn of 1962 most echoes were observed during the period 1900 to 2200 local time, very few echoes being observed outside of those limits. During the spring of 1963 the onset of direct back-scatter was rather later, but on a number of occuasions echoes continued to be seen up until midnight.

3.2 Correlation of direct back-scatter with spread-F

Vertical incidence ionograms taken at Accra were available from October 28, 1962, onwards, and hence it has been possible to make a day to day comparison between the occurrence

of spread-F and direct back-scatter. Such a comparison has been made on the basis of equatorial spread-F occurring between 1800 and 2400 G.M.T., and, as it is difficult to determine an index of intensity for spread-F, it has been made on the presence or absence of spread-F only. The comparison is presented in the form of a contingency table (Table 1), from which it may be seen that although there is a strong correlation between the occurrence of direct back-scatter and equatorial type spread-F (the probability of independence is less than 0.01), and scatter is never observed in the absence of spread-F, scatter is not invariably observed when spread-F is present.

		Spread-F	
		Present	Absent
Scatter	Present	26	0
	Absent	11	11

Table 1.

3.3 Height of irregularity patches responsible for direct back-scatter.

The height of a patch of irregularities may be determined when the patch is directly above the sounder, when the minimum range of the echo is equal to the height of the base of the patch.

As the frequency used for sounding is much greater than the plasma frequency the effect of group retardation on the measured range is negligible, and the heights measured are, to a close approximation, true heights. Fig. 6a shows how the mean height of patches varied with time for the autumn of 1962, and Fig. 6b shows the variation of the same parameter for spring 1963; h'F curves are shown for comparison. It may be seen that, during the autumn of 1962, the mean height of patches decreased from 460 Km. at 1945 G.M.T. to 390 Km. at 2145 G.M.T., and that the patches were located approximately 150 Km. above h'F. During the spring of 1963 the mean height of patches varied from 420 Km. at 2030 G.M.T. to 300 Km. at 2330 G.M.T., and up until 2200 G.M.T. the patches were again to be found 150 Km. above h'F, but after this time the base of the layer started to rise while the height of the irregularities continued to fall.

3.4 Size of irregularity patches.

The fact that echoes are obtained from the east and west, but not from the north or south is due to field alignment of the elongated irregularities responsible for the echoes, it being possible to observe direct back-scatter only when the wave-normal of the exploring wave is nearly perpendicular to the direction of elongation of the irregularities. As a consequence

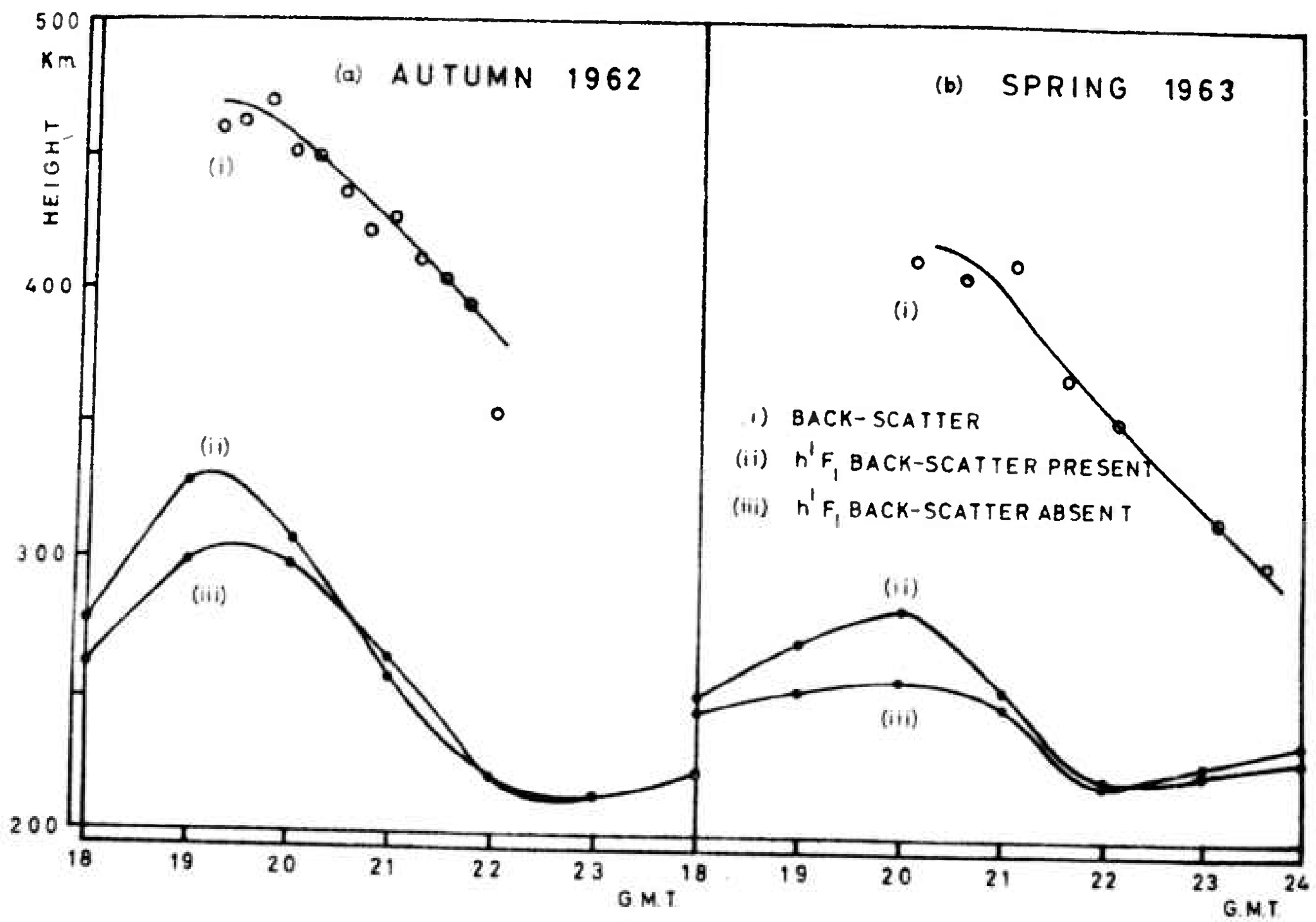

FIG.6 NOCTURNAL VARIATION IN HEIGHT OF IRREGULARITIES & IN h'F.

of the orthogonality requirement it is not possible to deduce, from the back-scatter measurements, anything about the north-south extent of the patches of irregularities, but the duration of the echo pulse does provide some information on the extent of patches in a direction normal to the direction of elongation. From the histogram shown in Fig. 7 it may be seen that the most probable duration is 1 mS., and hence, as the duration of the transmitted pulse is 0.3 mS., the broadening of the pulse is 0.7 mS., corresponding to a patch size of approximately 100 Km. The largest patches observed are of the order of 400 Km. in extent, and the smallest are 30 Km. or less; patches smaller than 30 Km. might well exist, but the resolution of the equipment was insufficient to measure such patches. It should be emphasised that these dimensions do not relate to individual irregularities, but to patches of irregularities.

If the cross-section of the patches is other than statistically isometric in the east-west vertical plane, then the duration of echoes would be expected to vary with their range, i.e. a horizontally flattened patch would produce an echo whose duration increased with range, and a vertically elongated patch would produce an echo whose duration decreased with range. The mean echo durations for various ranges, east and west, have been plotted in Fig. 8. From Fig. 8 it may be seen that there is very

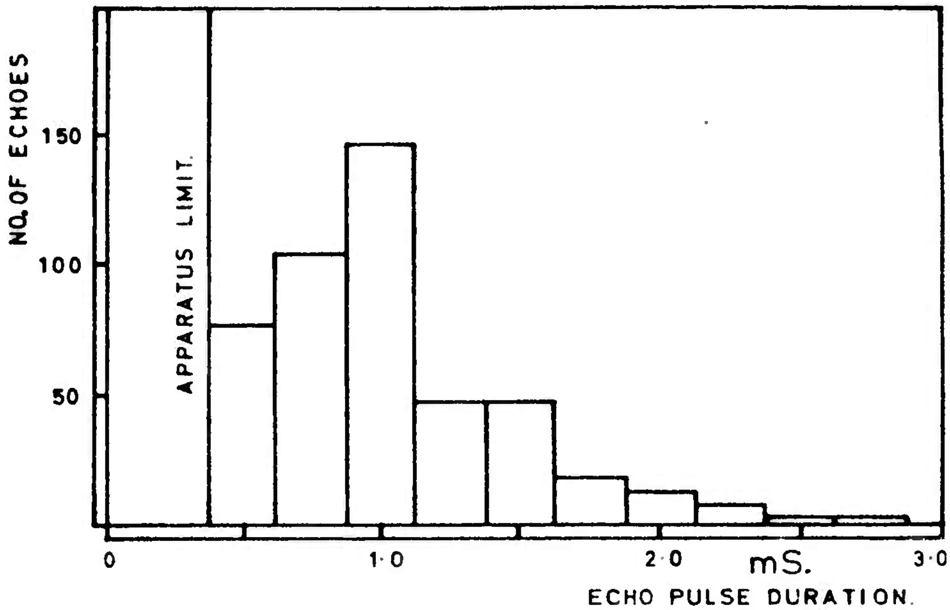

FIG. 7 DISTRIBUTION OF ECHO PULSE DURATIONS.

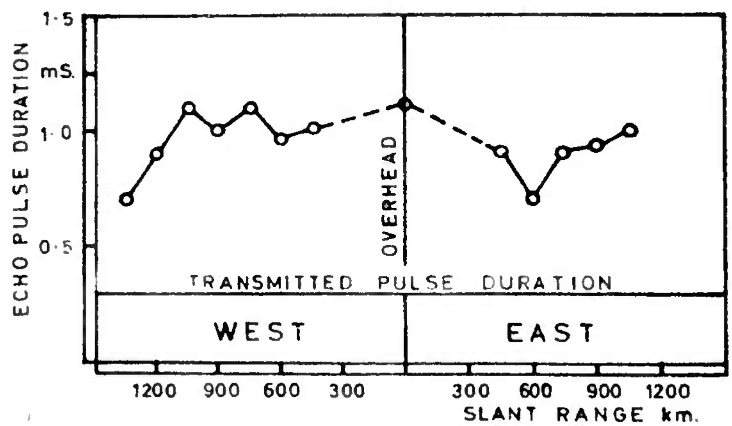

FIG. 8 VARIATION OF ECHO PULSE DURATION WITH RANGE.

little evidence of a systematic variation; the shortest durations occur at 1350 Km. west and 600 Km. east, and although this could be the result of tilted flat patches, the evidence is too little to warrant any serious consideration of this possibility. The conclusion which must be drawn from the results shown in Fig. 8 is that there is little indication that the patches are other than statistically isometric in the east-west vertical plane.

3.5 East-west distribution of echo occurrence.

When reducing the P.P.I. records for the autumn of 1962 it was noticed that many more echoes were obtained from the west than from the east, although no similar phenomenon was noted for the spring of 1963, or for the few observations made in the spring of 1962. In Fig. 9 the number of echoes returned from a given range, east or west, is plotted against range, for spring 1962, autumn 1962 and spring 1963. Fig. 9 shows that during the period September to December, 1962, between three and four times as many echoes were returned from the west as from the east, although approximately equal numbers were returned from east and west during the springs of both 1962 and 1963. It is most unlikely that this assymetry could be the result of a difference in the sensitivity of the sounder between east and west, both

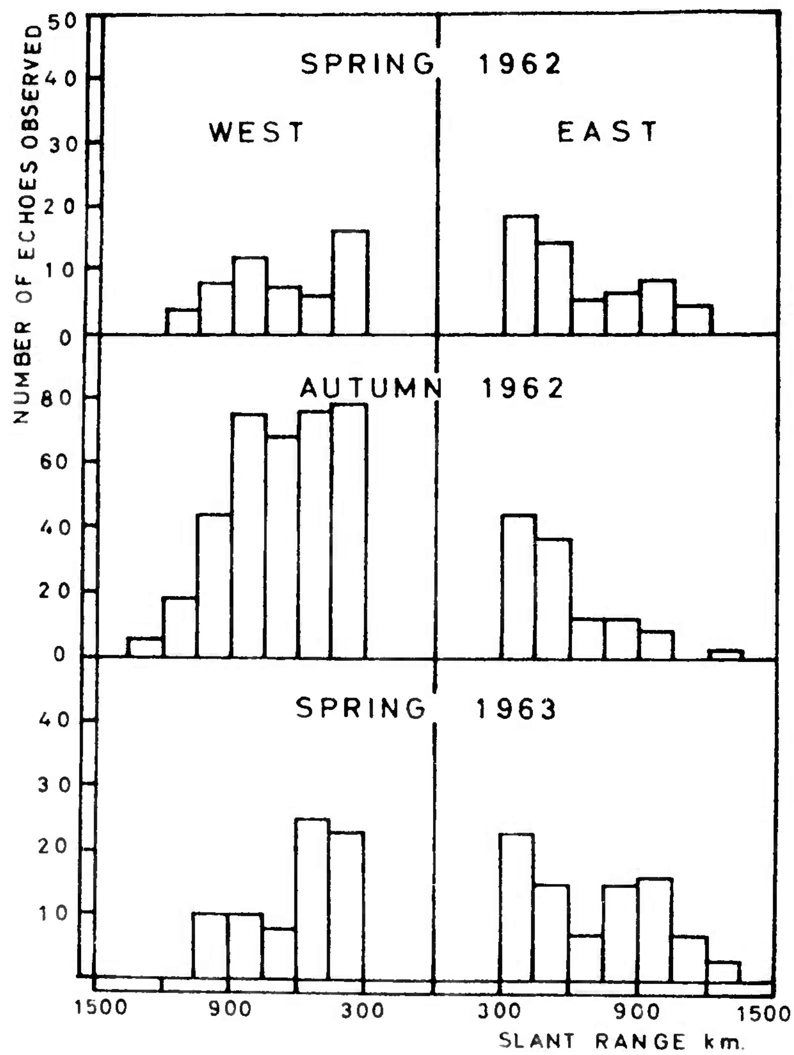

FIG. 9 VARIATION OF ECHO OCCURRENCE WITH RANGE.

because of its occurrence only in the autumn, and because there was no noticeable difference in the intensity of ground back-scatter echoes east and west. The simplest explanation of this east-west assymetry would be that there was a longitudinal variation in the occurrence of irregularities during the period in question, but this explanation is most improbable in view of the very rapid variation which would have to exist. The most likely explanation is that the irregularities exhibit an aspect sensitivity in the east-west vertical plane. This phenomenon will be considered in greater detail in section 4.

3.6 Lifetime of echoes.

The range/time records show the growth and decay of an echo, and thus make it possible to measure its lifetime. The lifetimes of some fifty echoes observed during the autumn of 1962 have been measured, and are shown in the histogram of Fig. 10. It may be seen from Fig. 10 that most echoes have lifetimes of ten to twenty minutes, but occasionally echoes are observed which endure for as much as ninety minutes. A few range/time measurements were made in the spring of 1963, and these showed on one occasion and echo which persisted for 150 minutes.

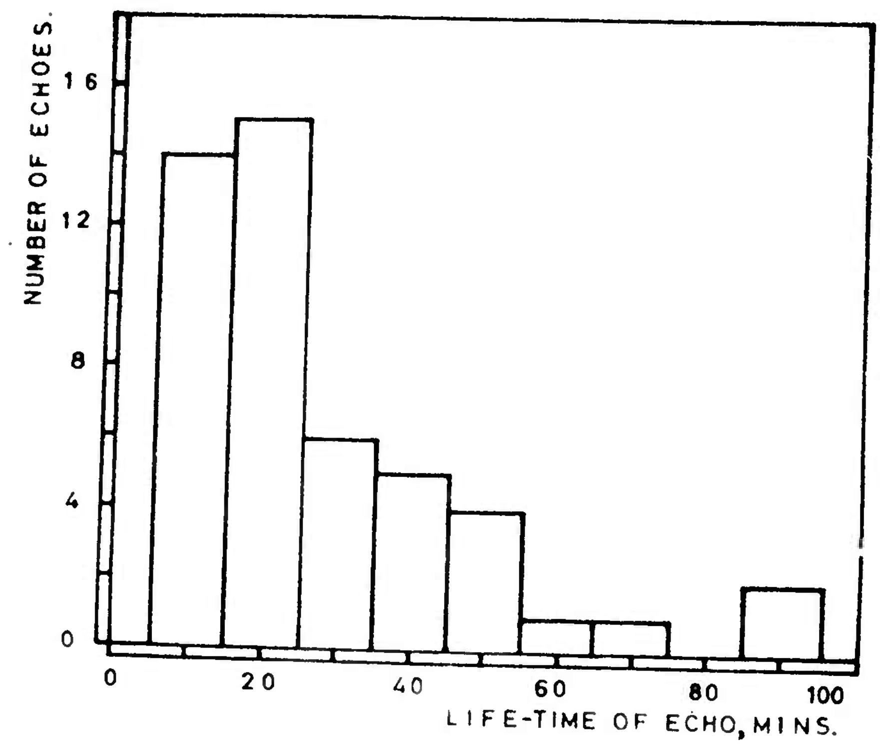

FIG.10 DISTRIBUTION OF ECHO LIFE-TIMES.

3.7 Drift of patches.

The component of velocity of a patch of irregularities towards or away from the sounder may be obtained from the range/time records by measuring tho slope of the echo trace. If it is assumed that the drift is horizontal then it becomos possible to calculate the horizontal velocity by assuming a height for the patch; the error introduced by assuming a height which may be as much as 100 Km. too high or too low is only appreciable when the patch is nearly overhead, and for this reason drift velocities were calculated only for patches it ranges of 600 Km. or more, where the error would not exceed 10%. Another, and more serious, source of error lies in the fact that in calculating velocities the ray path in the ionosphere has been assumed to be a straight line, whereas in fact, for patches more than about 600 Km. away, considerable refraction would occur, unless the patch is close to the base of the layer. The effect of this, in conjunction with the small amount of group retardation which tho wave suffers at heights near to h_m is to make the calculated velocitios too high by as much as 25%.

The median velocities, at local times from 1930 to 2330, have been calculated from a total of 48 measurements made during the autumn of 1963, and are plotted in Fig. 11. From Fig. 11 it may be seen that maximum velocities of about 130 m/s.

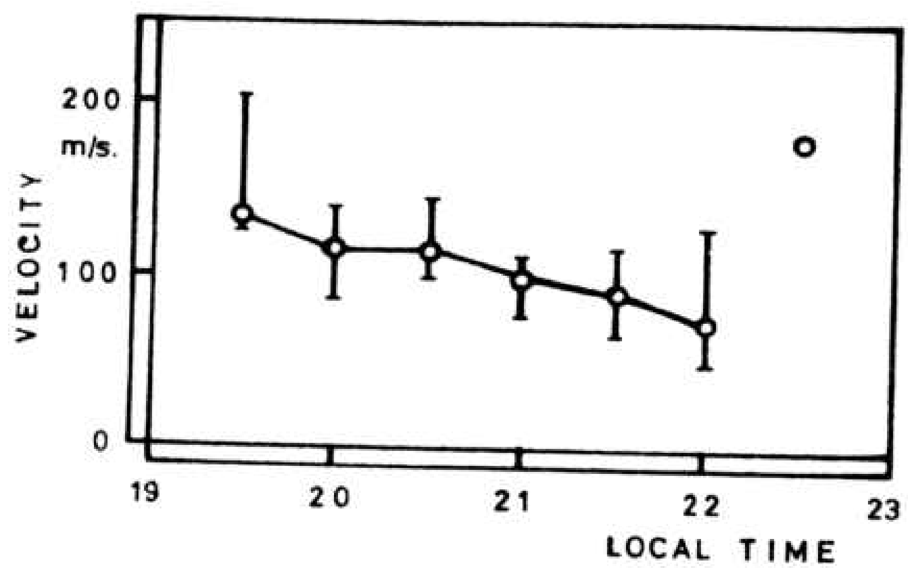

FIG.11 VARIATION OF DRIFT VELOCITY WITH LOCAL TIME.

occur shortly after the irregularities first appear at about 1930 local time, decreasing to 75 m/s. at 2200; the very high velocity at 2230 is based on two measurements only, and is probably not typical. Although the velocities shown in Fig. 11 may be as much as 25% to high, this applies equally well to all the velocities given, and so the decrease in velocity with time is probably real.

All the range/time measurements made during the autumn of 1962 showed a drift towards the east, on no occasion was the direction of drift reversed. In the spring of 1963 a few range/time records were taken, and on several occasions a drift towards the west was observed, although the normal direction was still towards the east. The velocities given in Fig. 11 are calculated on the assumption that the drift is horizontal, and it is important to attempt to determine whether or not this assumption is justified. It is possible to determine when a patch of irregularities is vertically above the sounder, for in this situation the echo strength is equal from all directions; if, under these conditions, the range/time records show zero rate of change of range with time, then the drift must be horizontal. Examination of the records showed that for all cases observed the rate of change of range with time was in fact zero when the patch was overhead; the limit of accuracy of the measurements was such that the minimum vertical velocity which would definitely have been detected was 25 m/s.

Another way in which a vertical velocity would manifest itself would be in a difference between the apparent horizontal velocities of patches to the east and west. The mean velocities for the measurements made in the autumn of 1962 are 120 m/s. east, and 103 m/s. west; the difference between those two values is too small to be considered significant. The conclusion to be drawn is, then, that any vertical component in the velocity of patches is less than 25 m/s.; however, the results of the doppler shift measurements throw some doubt on this conclusion, and this problem is discussed in section 4.

3.8 Doppler shift of echoes.

A few measurements of doppler shift were made towards the end of the autumn of 1962, and more measurements were made during the spring of 1963. The line of sight velocities obtained from the doppler shift measurements are plotted against range, east or west, in Fig. 12, which also shows the frequency spread of the echo signals.

The results shown in Fig. 12a were obtained on two nights; the three measurements for irregularities east of the sounder, and one to the west, being made on a single night. If the irregularities were travelling with uniform horizontal motion, then it would be expected that echoes from irregularities directly

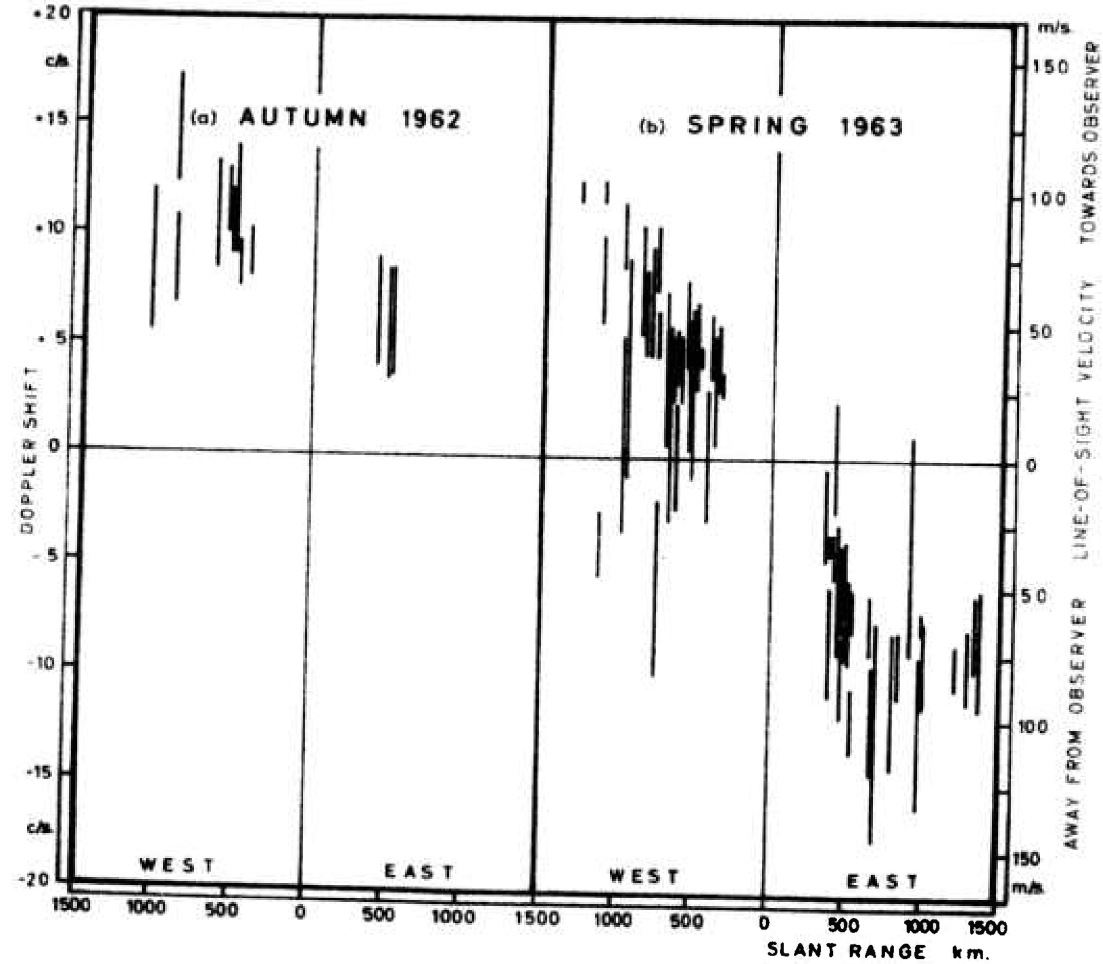

FIG.12 VARIATION OF DOPPLER SHIFT WITH RANGE OF ECHO.

overhead would give zero doppler shift, and that equal and opposite doppler shifts would result from irregularities at equal and opposite ranges, east and west; that this is not the case may clearly be seen from Fig. 12a. The values of doppler shift obtained during the autumn of 1962 indicate a vertical velocity component of about 70 m/s. directed downwards, in addition to an eastwards component of about the same magnitude. This interpretation of the doppler shift measurements is not, however, unique, and it would be possible to interpret them as being the result of a sudden reversal of drift, but in view of the rapidity with which such a reversal would have to occur, it would seem unlikely. Two measurements, made within 25 minutes of each other, showed large positive doppler shifts in each case, although one of the measurements was for irregularities to the east of the sounder, and the other for irregularities to the west. For these two measurements to be the result of a sudden reversal, the drift velocity would have had to change from approximately 50 m/s. towards the west, to nearly 100 m/s. towards the east, within a space of 25 minutes; such a rapid change is highly improbable. Reversal of the direction of drift of patches of irregularities has been noted during the spring of 1963, but not occurring sufficiently rapidly to explain the autumn doppler shift results in terms of such a reversal; no drift reversals were observed during the autumn of 1962.

Fig. 12b shows the results from doppler shift measurements made on 14 nights between 18th April and 20th May, 1963. These results indicate a more nearly horizontal motion than the results for the autumn of 1962, although the slightly higher velocities observed to the east suggest a small vertical velocity directed upwards.

The frequency spread of the doppler shifted echo signal could either be the result of a random component in the vector velocity of irregularities, or could be due to the fact that a patch of irregularities subtends an appreciable angle at the sounder, and hence the components of velocity of irregularities towards the sounder differ, according to the position of the irregularities in the patch. If the frequency spread were the result of the second of the two mechanisms suggested above, then it would be expected that the spread would decrease with increasing range, as the angle subtended by patches decreased; that this is not the case may be seen from Fig. 12, and hence it would appear that the frequency spreading is the result of a random velocity. In Fig. 13 frequency spread is plotted against local time, and it may be seen that the largest random velocities occur shortly after the irregularities first appear, at about 2000 local time. Attempts to correlate frequency spread with patch size and doppler shift both gave negative results.

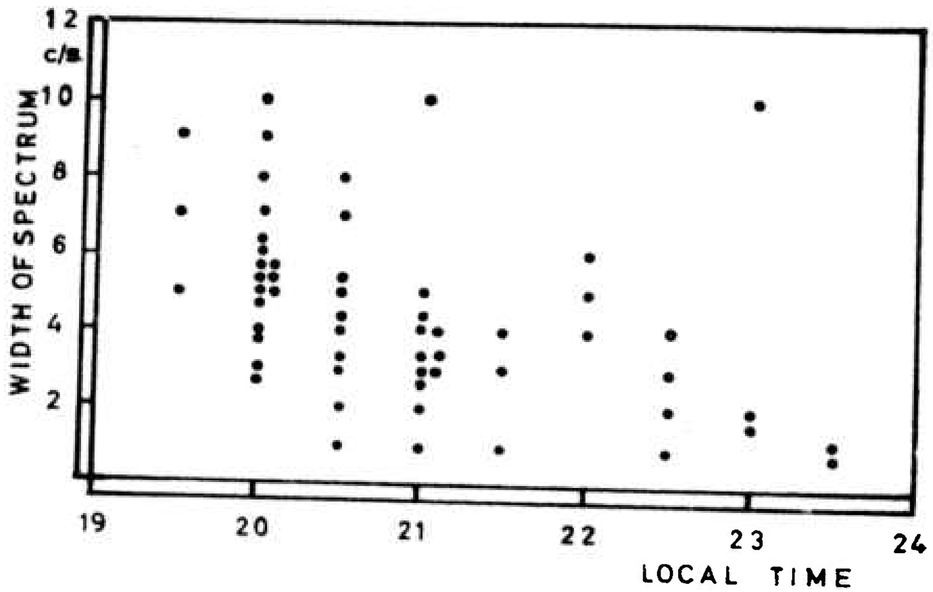

FIG. 13 VARIATION OF WIDTH OF FREQUENCY SPECTRUM OF ECHO SIGNALS WITH LOCAL TIME.

4. Discussion of results.

4.1 Occurrence of irregularities.

The occurrence of scatter producing irregularities during the early hours of the night, and the correlation with equatorial type spread-F, clearly show that the irregularities responsible for direct back-scattor are closely associated with those responsible for spread-F. The fact that direct back-scatter is not always observed when equatorial type spread-F appears to be present might be due to the fact that scatter at 18 Mc/s. would only be observed when fairly intense irregularities are present, and these irregularities would have to exhibit the appropriate spatial wavelength for this frequency.

Two phenomena, the nocturnal variations in occurrence of which closely correspond to that of direct back-scatter, are sunset flutter fading, and doppler shift of obliquely propagated signals. Calvert et. al (1962) have measured the doppler shift of signals propagated from Tripoli to Accra, and find that, during the evening hours, the normal smooth narrow trace on the frequency spectrum record spreads out to cover a range of 10 to 15 c/s.; they find the record to be most disturbed during the period 1900 to 2200 G.M.T. They also observe that there are striations running through the record, indicating one or more predominant frequencies which decrease with time; these they consider to be caused by scattering

from patches of irrogularities drifting from west to east. Koster (1963a) has reported that the rapid flutter fading, which obliquely propagated signals frequently suffer when they are reflected from the equatorial F region at times around sunset (Subba Rao and Somayajulu, 1949, Osbourne, 1951), occurs almost entirely during the period 1900 to 2300 local time for signals propagated between England and Accra, and that there is a pronounced maximum in the occurrence of flutter at, or shortly after, the equinoxes. Koster sugge sts that the rapid fading is due to the beating together of two signals, one propagated by a normal reflection process, and the other via a scatter mode, the signal propagated by the scatter mode having a doppler shift imposed upon it by the motion of the scattering irregularities. The flutter fading would therefore appear to be a consequence of the doppler shift, and thus both of these phenomena to be caused by scattering from field-aligned irregularities in the F region. The similarities in the time of occurrence, seasonal variation, and the eastward drift, all suggest that the irregularities observed by the doppler shift technique, and those responsible for flutter fading, are of the same nature as the irregularities which give rise to direct back-scatter.

4.2 Properties of irregularities.

The most immediately striking property of the irregularities giving rise to direct back-scatter is their occurrence in patches. Previous investigations have produced results which indirectly indicate a certain degree of patchiness (Kent, 1961, Calvert and Cohen, 1961), but the back-scatter observations appear to provide the first direct 'picture' of patches of irregularities. The motion of the patches is also directly indicated by the back-scatter measurements.

The vertical extent of a patch of irregularities is not to be determined with any great degree of accuracy from the back-scatter measurements, but the results given in section 3 indicate that it is of the order of 100 Km. Kent and Koster (1961) find that the thickness of the scattering layer causing scintillation of 108 Mc/s. satellite signals is not greater than 120 Km, and thus, within the limits of experimental error, the results using two very different techniques are in agreement. By correlating the occurrence of scintillation at different points along the path of a satellite, and by correlating scintillation with spread-F, Kent (1961) has obtained a value of approximately 100 Km. for the horizontal dimensions of irregularity patches, this again is in agreement with the back-scatter measurements. It is perhaps important to emphasise here that the irregularities giving rise

to 18 Mc/s. back-scatter are always observed in patches, and have never been observed to extend continously over the whole sky. An explanation as to why the irregularities should exist in patches must await an adequate theory for the origin of F region irregularities.

The mean height at which the irregularities responsible for direct back-scatter are observed is approximately 150 to 250 Km. above h'F up until 2200 local time, and somewhat lower after this time; this means that at least up until 2200 the irregularities are in the region of h_m. Kent and Koster (1961) have obtained values for the height of irregularities giving rise to scintillation of 108 Mc/s. satellite signals received at Accra during 1961, and during the evening hours they find heights between 380 and 420 Km. The heights measured by the back-scatter technique vary between 350 Km. and 450 Km., for the base of the irregularity containing region, and thus the agreement between the results obtained by the two techniques is fairly good.

The fact that the observed height of irregularities is close to h_m, and that changes in height of the layer are closely followed by the irregularities, is of interest, and warrants further consideration. The 'strength' of an irregularity in the ionosphere is usually considered as $\Delta N/N$, where $\Delta N+N$ is the electron density in the irregularity, and N is the ambient electron

density; the quantity which actually governs the amount of scattering is, however, $\Delta K/K$, where $\Delta K+K$ is the dielectric constant in the irregularity, and K is the ambient dielectric constant. For frequencies much greater than the plasma frequency, it may easily be shown that the dielectric constant K is approximately equal to unity, and ΔK is proportional to $-\Delta N$, and therefore $\Delta K/K$ is more nearly proportional to $-\Delta N$ than to $\Delta N/N$. The result of $\Delta K/K$ being approximately proportional to $-\Delta N$ is that if there are irregularities of approximately the same 'strength' $\Delta N/N$, distributed throughout the F region, then waves of frequency much greater than the plasma frequency will suffer the greatest degree of scattering at h_m, where N, and hence ΔN is a maximum. The fact that back-scatter measurements at 18 Mc/s. indicate the presence of irregularities in the region of h_m, is most probably not, therefore, indicative of any concentration of irregularities at such heights, but is merely the result of a wide distribution of irregularities of approximately the same 'strength' $\Delta N/N$. It should be remembered that this discussion is concerned with average heights, and average distributions of irregularities, and therefore that 'a wide distribution of irregularities' does not refer to the distribution at a given moment, but to the average distribution over a period of several months.

A number of workers have shown that there is a connection between F layer height and the occurrence of spread-F: Lyon ot. al. (1961) have shown that spread-F most frequently occurs when tho height of the base of the layer exceeds 400 Km.; Marasigan (1960) suggests that downward motion of the layer causos spread-F; and Singleton (1962) suggests that great height and downward motion both lead to spread-F. The downward motion favoured by Marasigan and Singleton is opposed by Lyon et. al., who consider that upward motion leads to spread-F. The results of tho back-scattor measurements tend to support the height and downward motion roquirements for the occurrence of irregularities. Back-scattor echoes were never observed before the layer started to fall, and occurred most frequently when the post-sunset rise was greatest (See Fig. 6). The seasonal variation in direct back-scatter echoes also fits in with these requirements, more echoes being observed in the autumn, when the post sunset rise of the F layer was greater, than in the spring, when it was less. Furthermore, the onset of irregularitios was later in the spring than in the autumn, as was the time at which the layer reached its maximum height. So far as the motion of the layor is concerned tho back-scatter results lend weight to the findings of Marasigan and Singleton, and opposo the findings of Lyon ot. al.; it must be remember, however, that tho back-scatter measurements should not be indentified too closoly with spread-F,

as irregularities at the base of the layer, leading to range spreading on ionograms, will not produce an appreciable amount of back-scatter at a frequency of 18 Mc/s.

It has been suggested by Martyn (1959) that electrostatic fields might be responsible for the formation of irregularities in the F region. Martyn has shown that the underside of the F region would be unstable to small perturbations when the layer is drifting upwards under the influence of an electrostatic field, and that the topside of the layer would be unstable when it is drifting downwards. It has been suggested that the required electrostatic field might originate in the E region, and be communicated to the F region by the geomagnetic field lines. Regardless of whether or not F region irregularities are the result of the mechanism proposed by Martyn, any motion of the irregularities relative to the layer could lead to their enhancement, as they drift into a region of increasingly different electron density. Some evidence that this enhancement does in fact occur is provided by the fact that more back-scatter echoes were observed during the autumn than during the spring. The doppler shift measurements made during the autumn showed a downward velocity of the order of 250 Km/hr. for the irregularities, whilst h'F fell only at the rate of about 50 Km/hr., thus indicating a considerable motion of the irregularities relative

to the layer. The spring measurements indicated that the irregularities had a vertical component of velocity of not more than 50 Km/hr. directed upwards, while h'F was falling at a rate of 50 Km/hr. or less. Thus during the autumn, when echoes were observed most frequently, the irregularities showed a vertical motion relative to the layer of about 200 Km/hr., whilst during the spring, when echoes were less frequent, this velocity was not greater than 100 Km/hr.

The drift velocity of patches (Fig. 10) varies from about 130 m/s. at 1930 local time, to 75 m/s. at 2200. Lyon et. al (1962) have measured drifts at Ibadan using the spaced aerial technique, and obtain values of about 80 m/s. during the period in question, nearly always directed towards the east, but very occasionally towards the west. The drift determined by the back-scatter technique was always towards the east during the autumn of 1962, but on several occasions during the spring of 1963, a westward drift was observed. The Ibadan workers find that the direction of drift changes from westward to eastward very rapidly at about 1930 G.M.T. and then steadily increases from about 50 m/s. at 2000 G.M.T. to 100 m/s. at 2300 G.M.T., thus although the velocity and direction of drift measured by the spaced aerial technique at Ibadan are very similar to those measured at Accra by the back-scatter method,

tho manner in which the velocity changes during the evening is different. Tho difference betweon the results of the two methods is not surprising when one considers that the back-scatter measurements wore made some four years after the spaced aerial observations; furthermore, most of the Ibadan measurements were made when spread-F was absent, and being made at fairly low frequencies were for irregularities at the base of the layer, the height of which was changing rapidly at the time in question.

The measurements made towards the end of 1961 by Calvert et. al. (1962), using the oblique incidence doppler shift technique, are in better agreement with the back-scatter results. The velocities of about 130 m/s. to 100 m/s. obtained by these workers are very similar to the back-scatter results, not only in magnitude and direction, but also in the decrease of velocity with time. Calvert and Cohen (1961) have deduced drift velocities of patches of irregularities from sequences of ionograms taken at Huancayo during 1960, they find rather higher velocities than those measured at Accra, decreasing from 200 m/s. to 100 m/s. after 2100 hours local time, but with lower velocities sometimes occurring at earlier times. The measurements of Calvert and Cohen do not agroe with the back-scatter results as well as thoso of Calvert et. al., but it should be remembered that they were made is South America, where the position of the magnetic equator is very different from its position in Africa.

The doppler shift measurements on direct back-scatter echoes indicate an eastward motion of the irregularities of the same order of magnitude as that of the patches. During the autumn of 1962 there appeared to be, in addition to the eastward velocity, a vertical component of about 70 m/s. directed downwards. The existence of a vertical velocity during the autumn of 1962 was deduced from the results of a few measurements only, and, without supporting evidence, might be considered to be the result of freak conditions. Strong support for the suggestion that a downward vertical velocity was a normal occurrence during the autumn is provided by the east-west assymetry observed during the same period, and consideration of these two properties of the irregularities leads to some interesting conclusions.

It was shown in section 3 that, during the autumn of 1962, a much larger number of irregularity patches was observed to the west than to the east. In order to explain this assymetry it is necessary to postulate either a very rapid change in ionospheric parameters from east to west, or an aspect sensitivity of the irregularities in the east-west vertical plane, in addition to the already well known north-south aspect sensitivity which results from the field-alignment of irregularities. It may be seen from Fig. 9 that, even for irregularities only a few hundred kilometres east and west of the sounder, there is a very marked difference in the frequency with which they are observed, and

hence, as it is extremely improbable that ionospheric parameters should change sufficiently over so short a distance, it is unlikely that changes in the ionosphere are the cause of the assymetry. In view of the above it would appear that the assymetry must be due to an aspect sensitivity of the irregularities themselves, in which case it is important to look for factors which might lead to such an aspect-sensitivity.

In order to simplify the problem it is possible to consider only patches which are seen at a particular elevation angle, say 45°; the problem then reduces to one of seeking a property of the irregularity which looks different according to whether it is viewed at an angle of 45° to the vertical from the east, or at a similar angle from the west. The only observed property of the irregularities which satisfies the conditions stated above is their direction of motion. The doppler shift measurements for the autumn of 1962 indicated that the irregularities were travelling, very approximately, in a direction at 45° to the horizontal, eastwards and downwards, and hence, when viewed from the east at an angle of 45° to the vertical, were travelling directly towards the sounder, and when viewed at a similar angle from the west, were travelling in a direction perpendicular to a line joining the irregularities to the sounder. Further evidence that the aspect-sensitivity is the result of a non-horizontal motion of the irregularities is provided by the fact that during the spring of 1963, when the

doppler shift measurements revealed little or no vertical motion, the east-west assymetry was also absent.

The motion of the irregularities cannot, of course, in itself be responsible for the observed aspect sensitivity, and it now becomes necessary to look for possible corollaries of the motion which might result in such a phenomenon. The aspect sensitivity, and its relationship to the direction of motion, indicate that the scattering cross-section of the irregularities is greatest in the plane perpendicular to their direction of motion. Two possibilities which might lead to such a maximum in the scattering cross-section are: (i) the motion of an irregularity across the geomagnetic field lines might lead to a non-uniform charge distribution within the irregularity, perhaps in the form of a polarisation charge; (ii) the irregularities might in fact be the result of a wave motion, perhaps similar to the plane acoustic wavefronts suggested by Bowles et. al. (1963) as being responsible for equatorial type Es. The second of these two possibilities appears to be the less likely, as the irregularities do not show any characteristic velocity, as would be expected if they were the result of a wave motion. This objection might, however, be overcome, if the F region as a whole were drifting with a variable velocity, for the doppler shift gives a measure of the motion of irregularities relative to the sounder, rather than the surrounding medium in which they are imbedded. A full analysis of either mechanism is beyond the scope of this paper.

The width of the frequency spectrum of the direct back-scatter echoes is extremely variable, and may be as great as 10 c/s., or too small to measure (less than 1 c/s.); the average width is about 4 to 5 c/s. If the frequency spreading is the result of a turbulent component in the velocity of irregularities, then this component would be of the order of 20 m/s. Koster (1963b) has measured the turbulent velocity for irregularities giving rise to scintillation of 52 Mc/s. radio star sign als, and obtains a value of 4.6 m/s. The difference between these two values is large, and it seems unlikely that it could be the result of random changes in conditions, or of a sunspot cycle variation (Koster's measurements were made some two years before the back-scatter measurements). A possible explanation of this discrepancy lies in the fact that the irregularities contributing to a direct back-scatter echo probably extend over a much greater area than those affecting the 52 Mc/s. radio star signals which Koster used for his measurements. Koster does not give any figures for the apparent increase, due to scintillation, in the angular extent of the radio star sources which be used, but it is probable that it was not more than a few degrees, corresponding to an area in the F region some 20 Km. across, whilst the average size of a patch causing direct back-scatter was 100 Km. Thus the size of a patch of irregularities contributing to scintillation of a radio star signal would be much less than the

size of a patch causing direct back-scatter. The fact that the apparent random velocity is also much smaller for scintillation than for back-scatter strongly suggests that this random velocity is not the result of small scale turbulence, but of a slow change in velocity taking place over a distance of at least 100 Km., or, if considered as being caused by turbulence, then the scale of turbulence must be at least 100 Km.

The fact that during the autumn of 1962 the irregularities exhibited a large vertical velocity whilst the patches did not appear to show any appreciable vertical motion, suggests that individual irregularities must be short lived compared with the life-time of the patch. If this is the case, then it must be concluded that the source of the irregularities moves horizontally, although the irregularities themselves, once formed, may have a vertical component of velocity. It has already been suggested that the irregularities are widely distributed throughout the F region, but, at frequencies much greater than the plasma frequency, only cause appreciable scatter at heights near to h_m. This observation suggests that the lack of a vertical component in the velocity of patches may be due to the fact that irregularities are only observed at heights in the region of h_m, and that an irregularity having an appreciable vertical velocity would only be in this region for a comparatively short time. However, this explanation is rather unsatisfactory in view of the short average lifetime of patches,

and the relatively small vertical distance which irregularities would move in such a time.

It is, of course, possible that the motions derived from either the range/time or the doppler shift measurements are in error. It has already been shown that the east-west assymetry in echo occurrence provides considerable support for the observed vertical motion of irregularities, and there would seem to be little doubt that the vertical motion does in fact exist: it is, however, worthwhile reconsidering the range/time measurements in the light of the implications of the east-west assymetry. This assymetry appears to be the result of anisometric irregularities, exhibiting a maximum scattering cross-section in the plane perpendicular to their direction of motion. In order to make a determination of line-of-sight velocity from the range/time records it is necessary that the patch should be observed for as long as possible. As a result of the anisometry of irregularities, the patches producing the strongest scatter, and hence probably producing scatter for the longest periods, would be those moving directly towards, or away from, the sounder. It may well be that on the occasions when long-lived patches were observed to the east of the sounder, the irregularities were moving upwards, although the usual motion was downwards; such patches would, of course, be selected for velocity measurements, and hence these measurements would give much the same velocities for east and west, and suggest a horizontal motion.

This selection process would not affect the doppler shift observations to the same extent as the range/time measurements, as in order to make a determination of doppler shift the echo need only be detectable for a few minutes.

It can only be concluded from the above discussion that there is some doubt as to whether or not the patches move with the same vector velocity as the irregularities; further experiment is required to settle this question.

5. Conclusions

(i) Irregularities capable of producing direct back-scatter of radio waves with a frequency of 18 Mc/s. occur in the F region during the evening hours, and are most frequently observed during the period 1900 to 2200 local time; the irregularities are first observed immediately after the F layer reaches its maximum height in the post-sunset rise. Most irregularities are observed between spring equinox and summer solstice, and autumn equinox and winter solstice, and they are observed more frequently during the autumn than the spring.

(ii) Irregularities are only observed when equatorial type spread-F is present, being observed on about two-thirds of such occasions.

(iii) The irregularities always occur in patches, which may be up to 400 Km. in extent in the east-west vertical plane, with a most frequently observed size of 100 Km.; the patches appear to have approximately equal vertical and horizontal extent. The lifetime of patches, as observed by the back-scatter sounder, varies from 10 to 150 minutes, with an average value of about 20 minutes.

(iv) The bases of the patches are usually to be found about 150 Km. above h'F, and their height varies nocturnally with h'F, and hence the patches are usually in the region of h_m.

(v) The patches are usually observed to drift from east to west, although a drift in the reverse direction is very occasionally observed. If the motion is assumed to be horizontal the drift velocity is found to decrease from about 130 m/s. at 1930 local time to 75 m/s. at 2200 local time.

(vi) The motion of irregularities, as distinct from that of patches, is not always horizontal. Doppler shift measurements made during the autumn of 1962 showed a vertical component of velocity of about 70 m/s. directed downwards, in addition to a horizontal component of about the same magnitude directed towards the east. During the spring of 1963 the vertical component was either absent, or much smaller and directed upwards.

(vii) The irregularities appear to be anisometric in the east-west vertical plane, as well as being elongated north-south. This anisometry appears to take the form of the irregularities showing a maximum scattering cross-section in the plane perpendicular to their direction of motion.

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